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BIOACCUMULATION OF HEAVY METALS IN MARINE BLUE CRAB (*Callinectes amnicola*) AND FRESHWATER CRAB (*Sudanonautes aubryi*)

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ABSTRACT

Crabs can be particularly sensitive to heavy metals because, typically, they inhabit benthic zones. In this study, selected heavy metals (Copper (Cu), Cadmium (Cd), Lead (Pb), Nickel (Ni), Arsenic (As), Zinc (Zn), Iron (Fe) and Chromium (Cr) were analysed in the organs/tissues (gills, hepatopancreas, gonads, stomach and muscle) of *Callinectes amnicola* and *Sudanonautes aubryi* samples collected from Akodo beach and Asejire reservoir respectively using Atomic Absorption Spectrophotometer. The results obtained showed that Cr had the highest concentration in the stomach of male *S. aubryi* (3.003 $mg.kg^{-1}$) and Cu (3.016 $mg.kg^{-1}$) in the gills of female *C. amnicola.* From the two study sites, it was observed that the concentration of As (0.064 $mg.kg^{-1}$, 0.131 $mg.kg^{-1}$), Cr (3.110 $mg.kg^{-1}$, 1.110 $mg.kg^{-1}$), Cd (1.220 $mg.kg^{-1}$, 1.110 $mg.kg^{-1}$) and Pb (2.085 $mg.kg^{-1}$, 1.003 $mg.kg^{-1}$) in crabs (*C. amnicola* and *S. aubryi*) respectively were above the range of WHO acceptable limit for consumption (As 0.0001 $mg.kg^{-1}$, Cr 0.050 $mg.kg^{-1}$, Cd 0.003 $mg.kg^{-1}$ and Pb 0.500 $mg.kg^{-1}$). Input of heavy metals into the aquatic environment occurs probably through anthropogenic activities such as municipal wastewater, antifouling measures, indiscriminate use of manure and fertilizers, disposal of household and manufacturing industrial wastes. It is therefore recommended that there is a need for bio-monitoring and constant re-evaluation of heavy metals in fish and shellfish resources from the two study sites considering the status and importance of Akodo Beach and Asejire reservoir to the society.

Keywords: Heavy metals, Bioaccumulation, *Callinectes amnicola*, *Sudanonautes aubryi*, Asejire Reservoir.

INTRODUCTION

The most advanced members of the phylum Arthropoda are crabs, which are essential components of the ecosystem (Karadurmus and Aydin, 2016). Crabs inhabit a wide variety of aquatic and terrestrial habitats. They are present in almost all water bodies, from mangrove swamps, and stagnant ponds, to fast-flowing rivers and the deep seas. The species, *Callinectes amnicola* is a well-known blue crab belonging to the family Portunidae. It is one of the most economically important crabs in Nigeria's brackish lagoons and the Atlantic, where it is a valuable resource in artisanal fisheries (Lawson and Oloko, 2013). In general, the species is regarded as a valuable source of protein and minerals in human and animal diets (Babatunde, 2008; Muse *et al.*, 2019). The chitinous exoskeleton can also be treated and used because it contains several

bioactive compounds such as chitin (used as a nutritional supplement, in the manufacture of biodegradable plastic, surgical thread, as well as an additive and in the manufacture of paper), pigments (used in the production of inks, paints, and cosmetics), and many more, like fatty acids and amino acids (Kandra, 2012; Muse *et al.*, 2017). Freshwater crabs (family Potamonautidae) are primarily nocturnal, preferring to remain hidden during the day in burrow shelters and foraging mostly at night. They are mostly omnivorous scavengers, mainly feeding on plant matter, live prey such as fish and prawns or dead aquatic macroinvertebrates that they encounter. The species, *Potamonautes* can be found beyond the freshwater body environment even among aquatic vegetation and in rice fields. By avoiding a high-current environment, they can inhabit flowing water (Akpaniteaku and Oguayo, 2019). The crabs also constitute an important food resource for many species of fishes, birds, caymans, turtles and mammals (Muse *et al.*, 2017).

Heavy metals are naturally occurring elements with a relatively high atomic number greater than 20 and atomic density above 5 $g.cm^{-3}$ and must exhibit the properties of metal (Ajayi *et al.*, 2022). Some heavy metals, such as copper, arsenic, and zinc, are necessary trace elements that play critical roles in a variety of biological processes as well as the human metabolism. Heavy metal pollution of aquatic environments caused by the discharge of chemicals from mining sites, manufacturing industries, and city wastes, is a worldwide concern because the metals may be accumulated by aquatic organisms from the water, sediments and their food (Ajayi *et al.*, 2022; Peterson *et al.*, 2002). Heavy metals are considered serious pollutants of the aquatic environment because of their toxicity, high persistence, being non-biodegradable, and tendency to bioaccumulate in organisms. Heavy metals could be circulated by blood in the body and accumulate in the target organs, and subsequently appear in toxic forms both for the organisms and humans who consume seafood (Wang *et al.*, 2005). The increase of the metal concentrations in the environment can be transferred to the organisms of the food chain which is damaging to aquatic animals and may ultimately cause death (Lorenzon *et al.*, 2001). It is rather of great concern that over 80% of the industries in Nigeria discharge their solid waste, liquid and gaseous effluent containing toxic concentrations of heavy metal into the environment without any prior treatment while just only 18% of industries in Nigeria undertake rudimentary recycling before disposal (Ajayi *et al.*, 2022). Some agricultural practices also contribute to the pollution of the aquatic environment through agrochemical runoffs, which find their way into the water bodies (Ajayi and Oyewole, 2023).

Benthic organisms are integral components of communities and vital elements of the food chain that are highly sensitive to ecological changes. Macrobenthic invertebrates can be advantageous as a pollution monitoring tool; they are relatively sedentary and represent exposure at the site of collection. Macroinvertebrates, as a food source, accumulate high levels of metals and provide a means of transferring potentially toxic elements to higher trophic levels (Peterson *et al.*, 2002; Turkmen *et al.*, 2006; Takarina and Adiwibowo, 2011).

Crabs can be particularly sensitive to heavy metals because, typically, they inhabit benthic zones. Heavy metals in blue crabs (*Callinectes amnicola*) and river crabs (*Sudanonautes aubryi*) are being

investigated in this study. This will provide information on the level of bioaccumulated metals- Chromium (Cr), Cadmium (Cd), Iron (Fe), Nickel (Ni), Zinc (Zn), Arsenic (As), Lead (Pb), and Copper (Cu) in selected organs in the two species and established whether the accumulated heavy metals are within the recommended safe limits for human consumption.

MATERIALS AND METHODS

Study Areas

Freshwater crab samples were caught from Asejire Reservoir on the Osun River in Oyo State, Nigeria. Asejire Reservoir located at the boundary between Osun and Oyo States, is about 24 km east of Ibadan between latitude (07°59'45''N - 07°36'25''N) and longitude (004°08'00''E - 004°13'33''E). The reservoir has an abundance of water supply which remains full throughout the year and this accounts for the presence of diverse species of fish and shellfish such as *Chrysichthys nigrodigitatus*, *Coptodon zillii, Lates niloticus, Macrobrachium vollenhovenii*, *Sudanonautes aubryi*, *etc*. The reservoir has a capacity of about 80 million litres per day, of which 80% is used for domestic purposes and provides potable water to the Ibadan metropolis and other nearby communities (Ajayi *et al.,* 2022). Marine blue crab samples were caught from Akodo Beach located about 22 km along the Lekki - Epe expressway in Ibeju-Lekki Local Government Area of Lagos State. It lies between latitude (06°25'50'' N - 06°26'30'' N) and longitude (003°55'30'' E – 003°56'00'' E). Akodo is a coastal fishing community characterised by artisanal fishermen. Diverse species of fish and shellfish such as *Ethmalosa fimbriata, Sardinella madarensis, Scomberomorus tritor, Thunnus albacares, Penaeus monodon, Farfantepaenus notialis, Callinectes amnicola, etc*. are abundant as catch in Akodo beach (Muse *et al.,* 2019). The landing site cum the marketing of the fish landed is on the sandy coastal beach. At the landing sandy beach, the fish specimens were transferred from the canoes by big trays and bowls to be landed in heaps on the sandy beach. The heaps were then sold to the middle-women fishmongers.

Sample Collection, Sorting and Preservation

A total of thirty-one live samples each of the blue crab (*Callinectes amnicola*) and the freshwater crab (*Sudanonautes aubryi*) were obtained from artisanal fishers in August and October 2022 at Akodo Beach and Asejire Reservoir respectively. The samples were transported in ice packed cooler to the Physiology laboratory of the Department of Zoology, Obafemi Awolowo University, Ile-Ife. Crabs were washed with distilled water and sorted by sex using the method and features described by (Muse *et al.*, 2017; 2019). The sexes were distinguished by the shape and size of the abdomen; and visual examination of the ventral side of the abdominal cavity. The males usually have a narrow apron while the females have a larger U-shaped apron. Morphometric features of each sample were taken and recorded appropriately with the use of a digital Vernier calliper and a digital weighing balance. Crab samples were preserved in the deep freezer prior to analysis.

Assessment of Heavy Metal in *Callinectes amnicola* and *Sudanonautes aubryi*

Crabs were dissected along the epibranchial corners to access the organs; the gills, hepatopancreas, stomach, gonad, and muscle. The dissected organs were thawed for two hours, weighed into a pre-weighed petri dish, and then dried at 80 °C

in a Gallenhamp hotbox oven. Sample weights were taken and recorded at the interval of 4 hours until a constant weight was obtained. Each of the dried samples was pulverized to fine particles using a mortar and sieved using a sieve of mesh size 0.02 mm. Subsequently, 0.5 g of each sample was digested in 5 mL of aqua reagent HCl and HNO_3 (3:1). The digested sample was filtered into a graduated cylinder and the filtrate was made up to 50 mL using distilled water. Model PG990 Atomic Absorption Spectrophotometer (AAS) was used to analyse the concentration of heavy metals (Arsenic, Cadmium, Chromium, Copper, Iron, Lead, Nickel and Zinc) in the samples.

Statistical Data Analysis

The data were analysed using IBM SPSS version 25 for descriptive analysis and one-way analysis of variance (ANOVA). Tukey HSD test was used to identify significant differences at $P < 0.05$ level of significance.

RESULTS

In this study, Arsenic (As), Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Lead (Pb), Nickel (Ni) and Zinc (Zn) in selected organs: gills, hepatopancreas, gonads, stomach and muscle of blue crab (*Callinectes amnicola*) and river crabs (*Sudanonautes aubryi*) were evaluated. In *C. amnicola*, as shown in Figure 1, the concentration of bioaccumulated heavy metals varied across the organs. In male *C. amnicola*, the gill had a significant ($p < 0.05$) higher concentration of Cr (1.133 ± 0.001) $mg.kg^{-1}$ and Cd (1.059 ± 0.002) $mg.kg^{-1}$. The hepatopancreas had a significant ($p < 0.05$) higher concentration of Fe (1.201 ± 0.007) $mg.kg^{-1}$. The gonad had a significant ($p < 0.05$) higher concentration of Cr (1.099 ± 0.004) $mg.kg^{-1}$ and Fe (1.130 ± 0.003) $mg.kg^{-1}$. The stomach had a significant ($p < 0.05$) higher concentration of Cd (2.255 ± 0.005) $mg.kg^{-1}$. The muscle had the highest accumulation of Cu (2.097 ± 0.007) $mg.kg^{-1}$ and Cr (3.110 ± 0.003) $mg.kg^{-1}$ which were statistically significant ($p < 0.05$). The concentration of heavy meals in male *C. amnicola* was in the following order: Hepatopancreas < Gill < Gonad < Stomach < Muscle. The concentration of Cr > Cd > Fe > Cu > Pb > Zn > As > Ni.

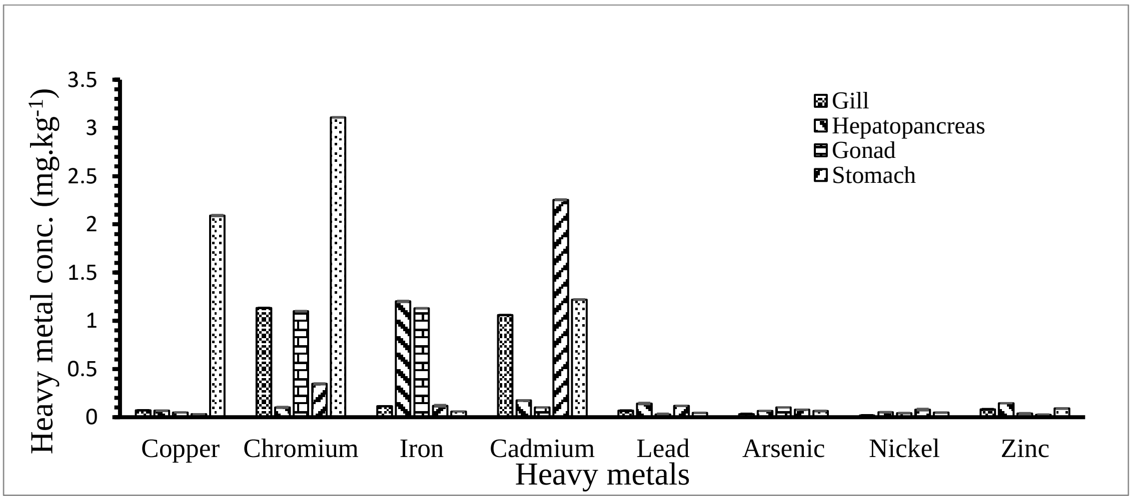

Figure 1: Heavy metal concentration in selected organs of male *Callinectes amnicola*

The analysis of heavy metal concentration in female *C. amnicola* is shown in Figure 2. The gills had a significantly high concentration of Cu (3.016 ± 0.001) mg.kg^{-1} ($p < 0.05$). The hepatopancreas accumulated higher Cr (1.223 ± 0.001) mg.kg^{-1} ($p < 0.05$). A significant ($p < 0.05$) high concentration of Cu (2.009 ± 0.001) mg.kg^{-1}, Cr (1.212 ± 0.004) mg.kg^{-1} and Pb (1.026 ± 0.006) mg.kg^{-1} were accumulated in the gonad. The stomach accumulated a staggering significant concentration of Cr (3.134 ± 0.004) mg.kg^{-1} and Fe (1.201 ± 0.001) mg.kg^{-1}. The muscle had a higher concentration of Cu (2.321 ± 0.002) mg.kg^{-1} and Pb (2.085 ± 0.005) mg.kg^{-1} which are statistically significant ($p < 0.05$). The concentration of heavy meals in female *C. amnicola* is in the order of: Hepatopancreas < Gill < Stomach < Gonad < Muscle. The concentration of Cu > Cr > Pb > Fe > Cd > Zn > Ni > As.

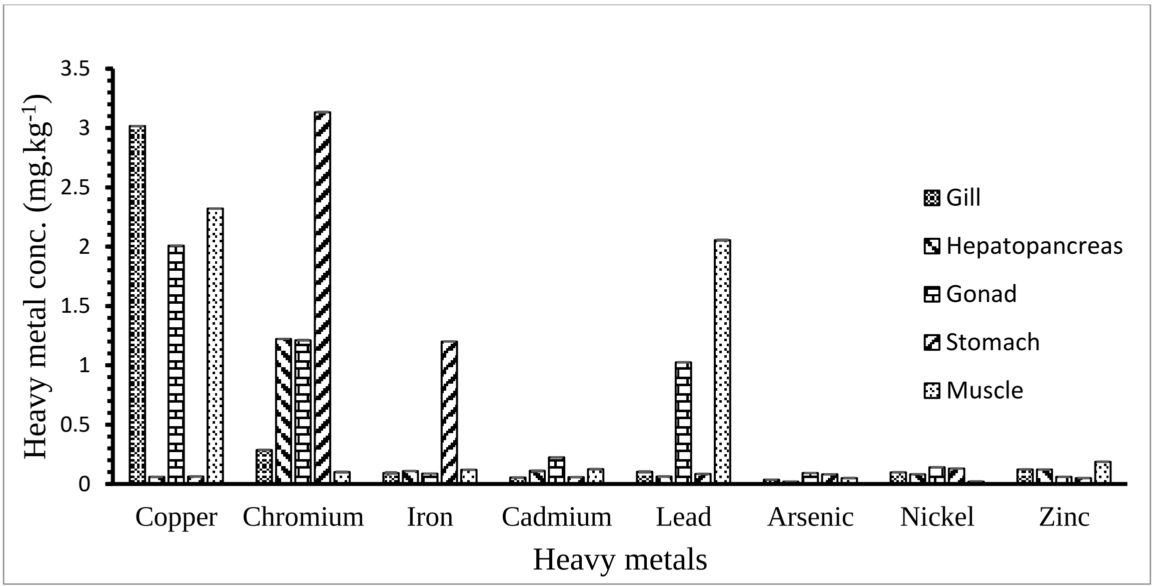

Figure 2: Heavy metals concentration in selected organs of female *Callinectes amnicola*

As shown in Figure 3, the concentration of bioaccumulated heavy metals varied across the organs in male *S. aubryi*. The gill accumulated more Fe (1.215 ± 0.004) mg.kg^{-1} than other organs, likewise the hepatopancreas accumulated a significant amount of Cu (1.220 ± 0.005) mg.kg^{-1} ($p < 0.05$). The concentration of Cd in the gonad (1.108 ± 0.008) mg.kg^{-1} was significantly higher than other metals. The stomach accumulated a significant level of Cr (3.003 ± 0.003) mg.kg^{-1} and Pb (1.043 ± 0.003) mg.kg^{-1} than other organs. The muscle accumulated the highest concentration of Cu (2.302 ± 0.002) mg.kg^{-1}, Cd (1.110 ± 0.002) mg.kg^{-1} and Zn (1.211 ± 0.001) mg.kg^{-1} which were statistically significant ($p < 0.05$). The concentration of heavy meals in male *C. amnicola* is in the following order: Gonad < Hepatopancreas < Gill < Stomach < Muscle. The concentration of Cr > Cu > Cd > Fe > Zn > Pb > As > Ni.

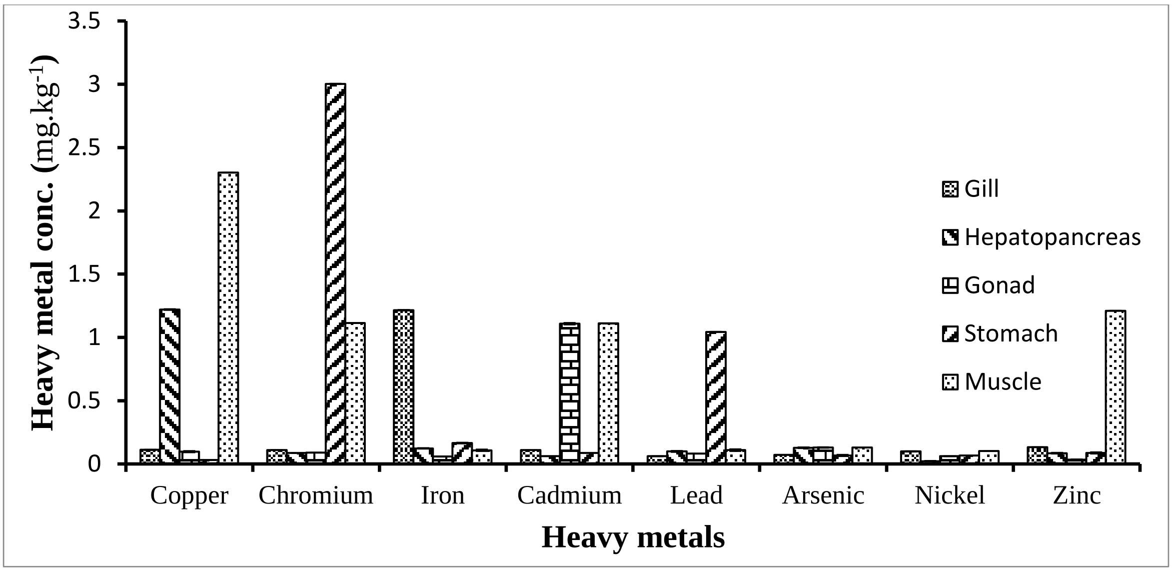

Figure 3: Heavy metals concentration in selected organs of male *Sudanonautes aubryi*

The results in Figure 4 showed the levels of bioaccumulated heavy metals across the selected organs in the female *S. aubryi*. The gills accumulated a significantly higher concentration of Ni (1.129 ± 0.004) $mg.kg^{-1}$. The hepatopancreas had a significantly high accumulation of Cr (2.231 ± 0.003) $mg.kg^{-1}$. The level of Cu (2.366 ± 0.006) $mg.kg^{-1}$ in the gonad was higher than in other organs while the stomach accumulated a higher concentration of Fe (1.118 ± 0.003) $mg.kg^{-1}$ than other organs. The muscle had the highest concentration of Pb (1.003 ± 0.003) $mg.kg^{-1}$ and Zn (1.205 ± 0.005) $mg.kg^{-1}$ than other organs ($p < 0.05$). The concentration of heavy metals in male *C. amnicola* is in the following order: Gill < Stomach < Gonad < Muscle < Hepatopancreas. The concentration of Cu > Cd > Ni > Cr > Fe > Zn > Pb > As.

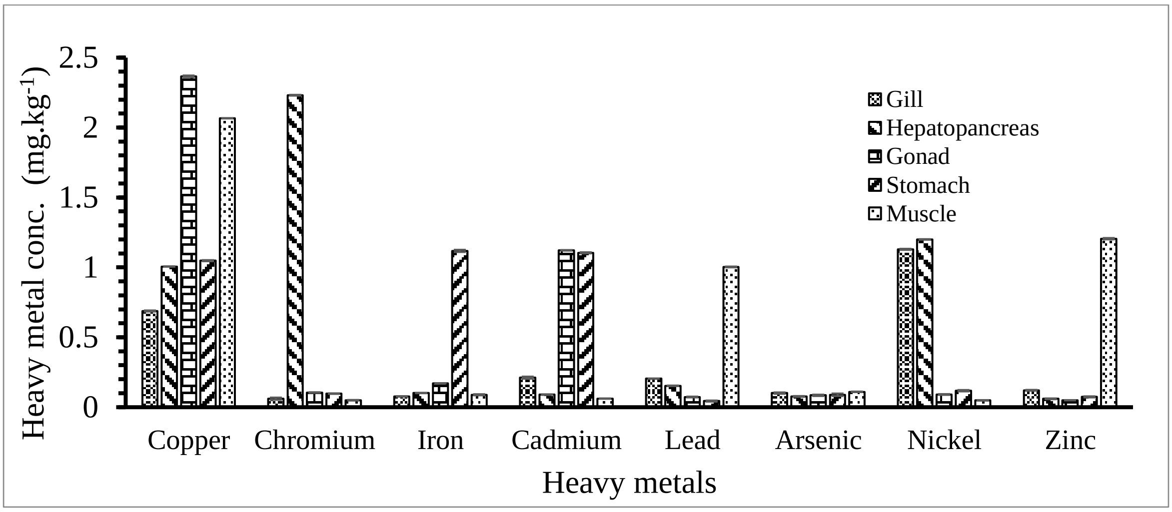

Figure 4: Heavy metals concentration in selected organs of female *Sudanonautes aubryi*

DISCUSSION

Heavy metals are of considerable health and environmental concern. They have been the subject of major studies because of their biotoxicity in the environment. Organisms high up in the food chain contain significant amounts of these metals as they concentrate them in their bodies. Generally, metals are neither rapidly removed from the environment nor readily detoxified or degraded by the metabolic activities of the organisms that absorb them; thus, resulting in bioaccumulation. Once absorbed, metals accumulate in specific organs rather than being distributed uniformly throughout the body (Ajayi and Oyewole, 2023). Hazardous waste discharge into the Nigerian environment is legendary since there is little or no recycling practices. Efforts by various regulatory agencies and non-governmental organizations (NGOs) seem to be inadequate in sensitizing and enforcement of laws that ensure proper disposal of toxic wastes and recycling of reusable wastes. The ultimate recipient of such waste is the waterbody known to be the habitat of many organisms including crabs. Crustaceans have a higher sensitivity towards heavy metals. Benthic feeders usually accumulate higher concentration of heavy metals in their body parts compared to the pelagic organisms (Bastami *et al*., 2012). Evaluation of heavy metal concentrations in *C. amnicola* (a marine species) and *S. aubryi* (a freshwater species) showed a significant difference in bioaccumulation across the organs i.e., the organs accumulate heavy metals differentially. Heavy metals bioaccumulate primarily in metabolic tissues such as the liver, pancreas, and gills. The hepatopancreas is an excellent indicator of heavy metal pollution because of its continuous exposure as it is the site for metabolism. The gills also take up and store metals in large quantities because it is the site for dissolved oxygen exchange between the crabs and the environment. Moreover, the gills have a wide surface area, which increases metal diffusion.

The bioaccumulation of heavy metals in aquatic macroinvertebrates is usually through food and water intake. High concentrations of Cr, Cd and Cu in the gills of male and female *C. amnicola;* and Fe, as observed in the gills of male *S. aubryi*, could be an indication that the gills serve as a site of active ionic exchange between the crabs and the external environment. Gills are often the main target of waterborne pollutants and are significantly prone to the accumulation of heavy metals due to continuous contact with the external environment. The occurrence of metal gill binding (especially Cu and Cd) has been reported in many fish species (Shah *et al.,* 2020; Soegianto *et al.,* 2023). The accumulation of high concentrations of heavy metals can cause damage to gills. Histopathological changes such as lamella fusion, epithelial necrosis, and hypertrophy have been reported as effects of heavy metals on gill structures in fish (Shah *et al.,* 2020; Alesci *et al.,* 2022). The hepatopancreas is the main storage site in crabs where nutrients are absorbed. This could have resulted in the high concentrations of Cr and Pb observed in the hepatopancreas of female *C. amnicola* and Cr in the hepatopancreas of female *S. aubryi*. In addition, the hepatopancreas of male *C. amnicola* accumulated a high concentration of Fe. The concentrations of Cr and Cd in *S. aubryi* from Asejire Reservoir and *C. amnicola* from Akodo Beach were far higher than the WHO (2001) acceptable limits of 0.0500 $mg.kg^{-1}$ Cr and 0.0030 $mg.kg^{-1}$ Cd in shellfish. Chromium toxicity may result in

hypertrophy and paraplegia of the gill epithelium (Aslam and Yousafzai, 2017). Chronic exposure to Cd has been linked to inducing oxidative stress, and impairing growth, reproduction, behaviour and development in aquatic organisms (Lee *et al.,* 2023).

It can be deduced that crabs serve as bio-indicators of persistent toxic metals and contaminants in aquatic environments because they are demersal and easily picks up sequestered heavy metals from the sediments. Heavy metals can be transferred and biomagnified via food chains and may threaten human health (Liu *et al.,* 2018). The concentrations of heavy metals in crabs indicate the level of metal pollution from the water from which it was caught. In the selected organs: muscle, gill, gonad, hepatopancreas and stomach, the metal observed to be of highest concentration in the crab was copper with a value of 3.016 $mg.kg^{-1}$ in the gill of female *C. amnicola*. The muscle of male *C. amnicola* had 2.097 $mg.kg^{-1}$, while in the muscle of male *S. aubryi* the concentration was 2.302 $mg.kg^{-1}$. The gonads of female of *S. aubryi* had 2.366 $mg.kg^{-1}$ of copper. Iron was observed to be more concentrated in the gill of males and the stomach of female *S. aubryi* from the aquatic environment. This may be due to the function of the stomach, which serves as the ultimate depository of all substances coming into crabs' alimentary canal. Chromium is the highest metal concentration observed in the stomach of female *C. amnicola* with a value of 3.134 $mg.kg^{-1}$ from Akodo beach. The concentration of Zinc in the muscle was higher in male and female *S. aubryi* than in *C. amnicola*. Zn was more concentrated in the hepatopancreas and muscle than in other organs.

In this study, Cu and Pb in female *C. amnicola* had a higher concentration than in the male *C. amnicola* indicating that female *C. amnicola* has a higher bioaccumulation tendency compared to the male. Moreover, the concentration of Cu in the gills and muscle of female *C. amnicola*, as well as in the muscle and gonad in male and female *S. aubryi* respectively are greater than the permissible limit (2.0 $mg.kg^{-1}$) of WHO (2001). The concentration of Cr in the stomach, gonad and hepatopancreas of female *C. amnicola*; muscle, gill and gonad of male *C. amnicola*; stomach and muscle of male *S. aubryi* and the hepatopancreas of female *S. aubryi* were greater than the permissible limit of WHO (2001). It was observed that the concentrations of As, Ni and Zn were lower compared to the concentration of other metals examined in these crab species. The WHO (2001) recommended a permissible limit of 0.0001 $mg.kg^{-1}$, 2.000 $mg.kg^{-}$1 and 3.000 $mg.kg^{-}$1 for As, Ni and Zn respectively. The high concentration of Cr in the gill and Cu in the stomach of female *C. amnicola*; Cu and Cr in the muscle of male *C. amnicola*; and the stomach and muscle of male *S. aubryi* and muscle and hepatopancreas of female *S. aubryi* were greater than other heavy metals in the organs indicating that the crabs had higher bioaccumulation tendency for Cu and Cr. However, the concentration of Fe in the two crab species was within the permissible limit (< 3.0 $mg.kg^{-1}$) of WHO (2001). The concentrations of heavy metals in crab organs showed significant differences between sexes of the crab species. The concentration of Pb in the stomach of male and the muscle of female *S. aubryi,* and in the hepatopancreas and muscle of female in *C. amnicola* exceeds the WHO (2001) permissible limit (≤ 0.5 $mg.kg^{-1}$).

The high concentrations of Fe and Zn in the crab organ could be associated with the fact that these metals are naturally

abundant in Nigerian soils. These metals get deposited in the aquatic ecosystems as contaminants from anthropogenic sources, atmospheric deposition, refuse incineration, domestic waste, and particulates possibly from automobile exhaust. It is not uncommon to find wastes of various types of metal-based materials such as cell batteries, electronic wastes, iron rods, food cans and enormous plastic wastes among others around rivers banks and shores where the crabs are found. Since these metal pollutants are nondegradable and resistant in the water bodies, bioaccumulation will likely occur because crabs absorb metals across body surfaces, and gill membranes and ingest food at a faster rate than they can metabolise and excrete them, leading to a net gain of the pollutants in their body. Heavy metals may decrease energy levels and impair the function of the brain, lungs, kidneys, liver, and other vital organs (Jaishankar *et al.,* 2014). Moreover, chronic exposure may lead to the gradual progress of physical and neuromuscular disorders, such as multiple sclerosis, Alzheimer’s disease, and muscular dystrophy (Fu and Xi, 2020). Furthermore, prolonged exposure to some metals and their compounds may cause cancer (Balali-Mood *et al.,* 2021). The toxicity level of a few heavy metals may be above the background concentrations that are naturally present in the environment. Therefore, a thorough knowledge of heavy metal concentrations is essential to the provision of proper defence measures against excessive contact with these hazardous elements.

Input of Copper (Cu) into the aquatic environment occurs probably through antifouling measures (such as boat painting and wood preservatives), indiscriminate use of manure and fertilizers, municipal wastewaters and manufacturing industrial wastes. Conversely, copper is the least expensive and most commonly used pesticide in the agriculture and other aquatic systems. Copper is recognized as an essential element, required by a wide variety of enzymes and other cell components having vital functions in all living things. However, excessive Cu intake will damage human health. Excessive Cu intake will cause poisoning, nausea, acute stomach pains, diarrhoea, fever, and induce oxidative stress (Oe *et al.,* 2016). Chromium plays a key role in glucose and lipid metabolism as an essential nutrient. The presence of chromium in food is of utmost importance as it is associated with insulin function and lipid assimilation (Ngala *et al.*, 2018). Zinc is fundamental in most metabolic pathways of humans, and its insufficiency leads to the loss of appetite, growth slowdown, skin mutation, and immunological dysfunction (Prasad, 2013). Nickel is often found in extremely small amounts in nature. However, anthropogenic activities such as smelting, vehicle emission, fossil fuel burning, disposal of household, municipal, and industrial wastes, fertilizer use, and organic manures all contribute to the nickel pollution of the aquatic environment and contributes to various pulmonary disorders, such as lung inflammation, dysfunction, emphysema, and tumours (Rehman *et al.,* 2018).

CONCLUSION

This study has shown that crabs are capable of bio-accumulating heavy metals to varying concentrations in all the organs examined. There is an indication of uneven distribution of the metals in the various organs examined, though there is a significant difference in metal distribution across the organs. In totality, only Zn, Fe,

and Ni were found to have concentrations below the accepted limited by WHO standard which depicts a high health risk in these organisms in relation to the environment under analysis. Thus, these results would suggest a bio-monitoring of the aquatic ecosystem in the study sites.

RECOMMENDATION

It is important that adequate monitoring of the water quality of the rivers should be consistently carried out. Appropriate measures such as legislative provisions and other tools for effective environmental monitoring should be put in place and enforced in order to protect and enhance the quality and resources of these water bodies.

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